GLACIOLOGY

Drillers for the University of Wisconsin's Ice Coring and Drilling Services (ICDS) clean ice out of the a recently reamed the hole so that they can fit seismic instruments into it. ICDS provides ice-coring and drilling services to NSF-sponsored researchers in the polar regions and at high-altitude sites. They maintain and operate a variety of drills and develop new systems when needed to provide the best possible ice cores, deploy instruments within the ice, and provide access to glacial beds. *(NSF/USAP photo by Kristan Hutchinson)*

Ice is indisputably the defining characteristic of Antarctica. The entire continent (with a few exceptions such as the McMurdo Dry Valleys and some lakes and mountains) is covered by a sheet of ice that has been laid down over eons, if the term "sheet" can be used to describe a dynamic mass that is several thousand meters (m) thick, that is larger than most countries, that rises over 2,000 m above sea level (and peaks in an ice dome nearly twice that high in the east), and that is heavy enough to depress the bedrock beneath it some 600 m. Actually, there are two sheets: the much larger East Antarctic Ice Sheet, which covers the bedrock core of the continent, and the smaller, marine-based West Antarctic Ice Sheet, which is beyond the Transantarctic Mountains and overlays a group of islands and waters.

The Glaciology program is concerned with the history and dynamics of the antarctic ice sheet; this includes research on near-surface snow and firn, floating glacier ice (ice shelves), glaciers, ice streams, and continental and marine ice sheets. These species of ice facilitate studies on ice dynamics, paleoenvironments (deduced from ice cores), numerical modeling, glacial geology, and remote sensing. Some current program objectives include the following:

- correlating antarctic climatic fluctuations (from ice-core analysis) with data from arctic and lower-latitude ice cores;
- integrating the ice record with terrestrial and marine records;
- investigating the physics of fast glacier flow with emphasis on processes at glacier beds;

- investigating ice-shelf stability; and
- identifying and quantifying the relationship between ice dynamics and climate change.

Dynamics and climatic response of the Taylor Glacier system.
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Taylor Glacier drains the Taylor Dome region of the East Antarctic Ice Sheet and terminates in Taylor Valley, one of the ice-free or dry valleys of southern Victoria Land. This glacier provides a crucial link between two intensively studied antarctic environments: the Taylor Dome, from which a 130,000-year ice-core paleoclimate record has recently been extracted, and the dry valleys, a pivotal ecological research site and a focus of geomorphology and glacial geology studies.

The goal of our research is to significantly improve our understanding of how Taylor Glacier flows and responds to changes in climate. It has been widely recognized that such information is central to understanding the changing physical environment of the Taylor Valley ecosystem and is required for linking interpretations of the Taylor Dome paleoclimate record to interpretations of the geomorphology and glacial geology of the dry valleys. This work will thus make an important contribution to ongoing efforts to exploit the Taylor Dome-dry valleys system to build a uniquely comprehensive view of regional long-term environmental changes.

Our work has two complementary components: field research and numerical modeling. Two field seasons will be used to measure velocity, surface strain rate, mass balance, ice thickness, glacier bed reflectance, and subglacial topography along a nearly complete longitudinal transect of the Taylor Glacier and along select cross-valley transects as well. This information will be used to constrain numerical models of ice and heat flow for the Taylor Dome-Taylor Glacier system. These calibrated models will be used to analyze the time-dependent response of the glacier to changes in climate. The synthesis of these results will be aimed at improving our understanding of the glacial geomorphology of Taylor Valley and at illuminating impacts on the Taylor Valley lakes ecosystem. (IO-161-O; NSF/OPP 01-25579)

Characteristics of snow megadunes and their potential effects on ice-core interpretation.
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Vast portions of the east antarctic plateau are covered by snow megadunes: trough-and-crest features that appear to result from vigorous surface-atmosphere interaction. A study of these features will lead to an improved understanding of their formation and characteristics, which may help identify megadune-altered ice in ice cores.

Megadune extent today is 500,000 square kilometers (km). The climatology of dunefields, characterized by low accumulation and consistent katabatic winds, suggests that they may have been even more extensive in the past. Megadunes have amplitudes of 2 to 5 meters and wavelengths of 2 to 5 kilometers, and are slightly asymmetric, with shorter upwind faces. The crests, up to 100 km long, are perpendicular to local katabatic wind flow. Satellite images show that the dune pattern remains unchanged for decades. Near-zero accumulation rates imply that snow remains near the surface and susceptible to modification for many years, both through surface exposure and subsurface ventilation. We suspect that megadunes are formed by a sublimation/vapor-redeposition process that operates in a standing wave airflow pattern set up over the snow. The climate record eventually preserved beneath dunefields is thus unlikely to represent the regional conditions of deposition, but the degree of modification is unknown.

Over two successive seasons, we will study an area within the large, well-developed megadune field southeast of Vostok Station (now closed). Our objectives are to determine the physical characteristics of the firn across the dunes and to install instruments to measure the time variation of near-surface wind and temperature with depth to test and refine our hypotheses on megadune formation. Field study will consist of surface, snowpit, and shallow core sampling; ground penetrating radar profiling; topographic and ice-motion surveys; automatic weather station installation; accumulation/ablation measurements; subsurface temperature; and firn permeability.

We will also continue our remote-sensing study of the dunes continent-wide, as well as earlier studies of dune characteristics, and will model diffusion, ventilation, and vapor transport processes within the dune firn as well.

Megadunes are a manifestation of an extreme terrestrial climate (the limit of cold and dry) and may provide insights on past terrestrial climate or processes active on other planets. Megadunes are likely to represent an end-member in firn diagenesis and as such may have much to teach us about the processes involved. (IO-186-O; NSF/OPP 01-25570; NSF/OPP 01-25276; NSF/OPP 02-25992; NSF/OPP 01-25960)

Millennial-scale fluctuations of dry valleys lakes: Implications for regional climate variability and the interhemispheric (a)synchrony of climate.
Brenda L. Hall, University of Maine, and Glenn Berger, Desert Research Institute, University of Nevada.

What drives glacial cycles? Most researchers agree that Milankovitch seasonal forcing paces the ice ages, but how these changes are leveraged into abrupt global climate change remains unknown. A current popular view is that the climate of Antarctica and the Southern Ocean leads that of the rest of the world by a few thousand years or more. The character of deglaciation in Antarctica is that of a long gradual warming, rather than an abrupt change, although the paleoclimate record is not well defined. The most persistent challenge to the asynchrony hypothesis is the Taylor Dome ice core. Revision to the chronology has shown that the original interpretation of rapid climate change synchronous with deglaciation in Greenland was probably an artifact of very low accumulation rates.

Millennial-scale fluctuations of high-level, closed-basin, amplifier lakes in the dry valleys of Antarctica can shed some light on this issue: 150 radiocarbon dates of algae from deltas and shorelines record rapid oscillations of these high-elevation lakes that extend through the Holocene. This record has the potential to form an independent data set with which to test the synchrony of abrupt climate changes in Antarctica. However, this approach has several shortcomings, including the fact that the record in the Holocene and earlier is unclear, a lake-level record based on geomorphological features alone is discontinuous, and only levels higher than the present lakes are recorded.

The ideal way to address these problems is to integrate the geomorphological record with a series of cores taken from lake bottoms. We will obtain transects of long cores from Lakes Fryxell, Bonney, Joyce, and Vanda, using an approach designed to extract the greatest possible amount of data. Estimates of hydrologic changes will come from different proxies. Chronology will come from dating of carbonates, as well as luminescence sediment dating. Evaluation of the link between lake level and climate will come from modeling

Combination of the more continuous lake-core sequences with the spatially extensive geomorphological record will result in an integrated data set that extends back at least 30,000 years. This record will be compared with dry valley glacier records and ice cores to address questions of regional climate variability and then with other Southern and Northern Hemisphere records to assess the interhemispheric synchrony or asynchrony of climate change. (IO-196-M; NSF/OPP 01-24014 and NSF/OPP 01-24049)

Characterizing the onset of ice-stream flow: A ground geophysical experiment.
Sridhar Anandakrishnan and Richard B. Alley, Pennsylvania State University; Donald D. Blankenship and David L. Morse, University of Texas-Austin.

The goal of the onset experiment is to gain a better understanding of the transition zone of antarctic ice streams, where they switch from flow by internal deformation to flow dominated by basal sliding. We are conducting a tightly coupled suite of seismic, ground radar, and global positioning system (GPS) surveys of the onset regions of two west antarctic ice streams. Our goal is to characterize the englacial and subglacial environment within the ice stream, to the sides of the ice stream, and upflow of the onset of streaming, as well as across the transitions that separate these dynamic regimes. Our target sites for this program are the onsets and regions of major flow-reorganization of ice streams C and D.

For the antarctic ice streams of the Siple Coast, we define the transition from no-sliding (or all internal deformation) to motion dominated by sliding as the onset-region. To fully understand (and adequately model) the West Antarctic Ice Sheet, this onset region must be better understood. The lateral margins of the ice streams are also transitions that need to be better understood-they are conceivably subject to hypotheses similar to those for the onsets. The definition of the onset region is necessarily ambiguous because the formation of the ice streams is so poorly understood. The physical manifestation of the onset of streaming may be a change in the velocity (a peak in acceleration), a change in driving stress, or both. The relationship between glacial and subglacial parameters (bed roughness, bed wetness, fabric) and the onset is not known.

Hypotheses on controls of the location of the onset region range from the purely glaciologic to the purely geologic; the answer is likely to be some combination of the two. One purely glaciologic hypothesis asserts that the basal water layer thickness increases sufficiently to drown controlling obstacles at the bed and ice streaming then occurs. For this hypothesis, the boundaries of the catchment of the ice stream, the basal hydrologic potential, and the driving stress are the parameters that control both the onset and the margins of the ice stream. Thus, to model the ice sheet effectively, a detailed surface and bed topography map, an accumulation map, and geothermal heat flux would be needed.

The other extreme, a purely geologic hypothesis, would argue that the onset position and margins of the ice streams are entirely controlled by the subglacial sedimentary structure and properties. The sedimentary basins would determine where there are erosional source regions to produce till, which, when mobilized and of sufficient thickness, would cause the ice stream to form. Therefore, to model the ice sheet, we need a good subglacial geologic map showing the distribution, thickness, and properties of the sedimentary basins, which can be estimated from seismic and other geophysical work.

This work is being done in collaboration with the British Antarctic Survey, and we have received technical support, personnel, and equipment from the Incorporated Research Institutions for Seismology/Program for Array Seismic Studies of the Continental Lithosphere seismic instrument pool and the University Navstar Consortium GPS instrument pool. (IO-205-O; NSF/OPP 00-86297)

Western divide WAISCORES (Western Antarctic Ice Cores) site selection.
Howard B. Conway and Edwin Waddington, University of Washington.

The West Antarctic Ice Cores (WAISCORES) community has identified the western divide, between the Ross embayment and the Amundsen Sea, as the region for the next deep-ice core. The Ice Core Working Group (ICWG) has developed a document (*WAISCORES: Science and Implementation Plan, 2000*) that outlines the objectives of the drilling and the physical and chemical properties the core must have to achieve those objectives.

The divide region spans more than 40,000 square kilometers, and preliminary site selection using airborne geophysical methods is now underway. This work has identified several potential drilling sites where the climate record should be best preserved throughout its long history of ice dynamics. We will make a suite of ground-based geophysical measurements to map spatial variations of iceflow, accumulation rate, internal layering, and ice thickness at two of the most promising sites. Our main investigative tools are high- and low-frequency ice-penetrating radar, repeat global positioning system surveys to calculate the present-day surface velocity field, synthetic aperture radar interferometry to calculate the regional velocity field, and short firn cores to calculate present-day accumulation rates.

Beyond the initial mapping and interpretation of internal layers and surface velocity, the measurements will be used to constrain our iceflow modeling. In particular, we will use these measurements and models to identify the specific site that is most likely to satisfy the following ICWG criteria:

- minimal disturbance from an iceflow,
- a record that extends back at least 50,000 years, and
- countable annual layers back 20,000 years.

A fourth criterion (good preservation of chemical species) will be addressed by others.

The first criterion (minimal disturbances) will be evident from the patterns of radar-detected internal layers. To address the other two, we will use the measurements as input for time-dependent iceflow and temperature models that predict depth variations of age, layer thickness, and temperature. The mismatch between the model predictions and the data eventually recovered from the core will help infer thinning and climate histories for the region, in addition to yielding an estimate of expected conditions before drilling. The information we gather will help guide site selection for the drilling. (IO-209-O; NSF/OPP 00-87345)